IS 7443 (2002): Methods for Load Rating of Worm Gears [PGD 31: Bolts, Nuts and Fasteners Accessories]

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भारतीय मानक

वर्म गियर की भार निर्धारण पद्धति

(पहला पुनरीक्षण)

Indian Standard

METHOD FOR LOAD RATING OF WORM GEARS

(First Revision)

ICS 21.200

BUREAU OF INDIAN STANDARDS
MANAK BHAVAN, 9 BAHADUR SHAH ZAFAR MARG
NEW DELHI 110002

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Price Group 6

Gears Sectional Committee, BP 13

FOREWORD

This Indian Standard (First Revision) was adopted by the Bureau of Indian Standards, on the recommendation of the Gears Sectional Committee and approval of the Basic and Production Engineering Division Council.

This standard was originally published in 1974. This revision has been undertaken to align the standard with BS 721 : Part 2 : 1983 'Specification for worm gearing : Part 2 Metric units' issued by the British Standards Institution.

This standard has been prepared to rationalize the power rating of machine cut worm gears. The allowable loads on a pair of gears are calculated on the assumption that deflection of worm shaft does not exceed 0.3 percent of worm diameter. It also assumed that gear housing has adequate housing and lubricating facility.

In this revision formulae of power, units of torque and Table 1 stress factors for worm gears S_b and S_c have been changed. The stress factors namely, bending stress factor and surface stress factor have also been reviewed and the values which are more applicable to the types of materials in use have been included in the revision.

In the preparation of this revision, assistance has been derived from BS 721 : Part 2 : 1983 issued by British Standards Institution (BSI), U.K.

For the purpose of dimensions for worm gearing, and the applicable tolerances reference may be made to IS 3734 : 1983 'Dimensions for worm gearing (*first revision*) and IS 11863 : 1986' Tolerances for worm gears' respectively.

In reporting the results of a test or analysis made in accordance with this standard, if the final value, observed or calculated, is to be rounded off, it shall be done in accordance with IS 2 : 1960 'Rules for rounding off numerical values (*revised*)'.

Indian Standard

METHOD FOR LOAD RATING OF WORM GEARS
(First Revision)

1 SCOPE

This standard covers the method for load rating of worm gears of involute helicoidal tooth form.

2 REFERENCES

The following standards contain provisions which through reference in this text, constitute provision of this standard. At the time of publication, the editions indicated were valid. All standards are subject to revision, and parties to agreements based on this standard are encouraged to investigate the possibility of applying the most recent editions of the standards indicated below:

IS No.	*Title*
2458 : 2001	Vocabulary of gear terms —Definitions related to geometry (*first revision*)
2467 : 1963	Notation for toothed gearing
3734 : 1983	Dimensions for worm gearing (*first revision*)
5267 : 1969	Glossary of terms for worm gears
7403 : 1974	Code of practice for selection of standard worm and helical gear boxes

3 TERMINOLOGY

The definitions and notations used in this standard are the same as given in IS 2458, IS 2467 and IS 5267.

4 SYMBOLS, NOMENCLATURE AND UNITS

Symbols	*Description*	*Units*
b	Worm wheel effective face width	mm
c	Clearance	mm
d	Reference diameter	mm
d_a	Tip diameter	mm
l_r	Length of root of the worm wheel teeth	mm
m	Axial module	mm
n	Speed of rotation	min^{-1}
n_m	Mean speed	min^{-1}
q	Diameter factor	—
t	Running time	h
t_{bm}	Average running time for strength	h
t_{eb}	Total equivalent running time for strength	h
t_{ec}	Total equivalent running time for wear	h
t_{cm}	Average running time for wear	h
v_s	Rubbing speed	m/s
z	Number of starts or teeth	—
E	Percentage efficiency	—
P	Load	N
S_b	Bending stress factor	—
S_c	Surface stress factor	—
T	Torque	Nm
T_b	Permissible torque for strength	Nm
T_{bm}	Occasional momentary load for strength	Nm
T_c	Permissible torque for wear	Nm
T_{cm}	Occasional momentary load for wear	Nm
X_b	Speed factor for strength	—
X_e	Speed factor for wear	—
Y_z	Zone factor	—
τ	Lead angle for the worm threads	deg
ϕ	Friction angle	deg

NOTE — Suffix 1 for worm and suffix 2 for worm wheel are used with the above notions wherever applicable.

5 REQUIREMENTS

5.1 Rubbing Speed

The rubbing speed V_s (in m/s) is given by :

$$V_s = 0.000\,052\,4\, d_1\, n_1 \,\mathrm{Sec}\,\tau$$

and

$$V_s = 0.000\,520\,4\, m\, n_1 \sqrt{(z_1^2 + q^2)}$$

The rubbing speed shall be limited to 12.5 m/s (for splash lubrication).

5.2 Speed Factor

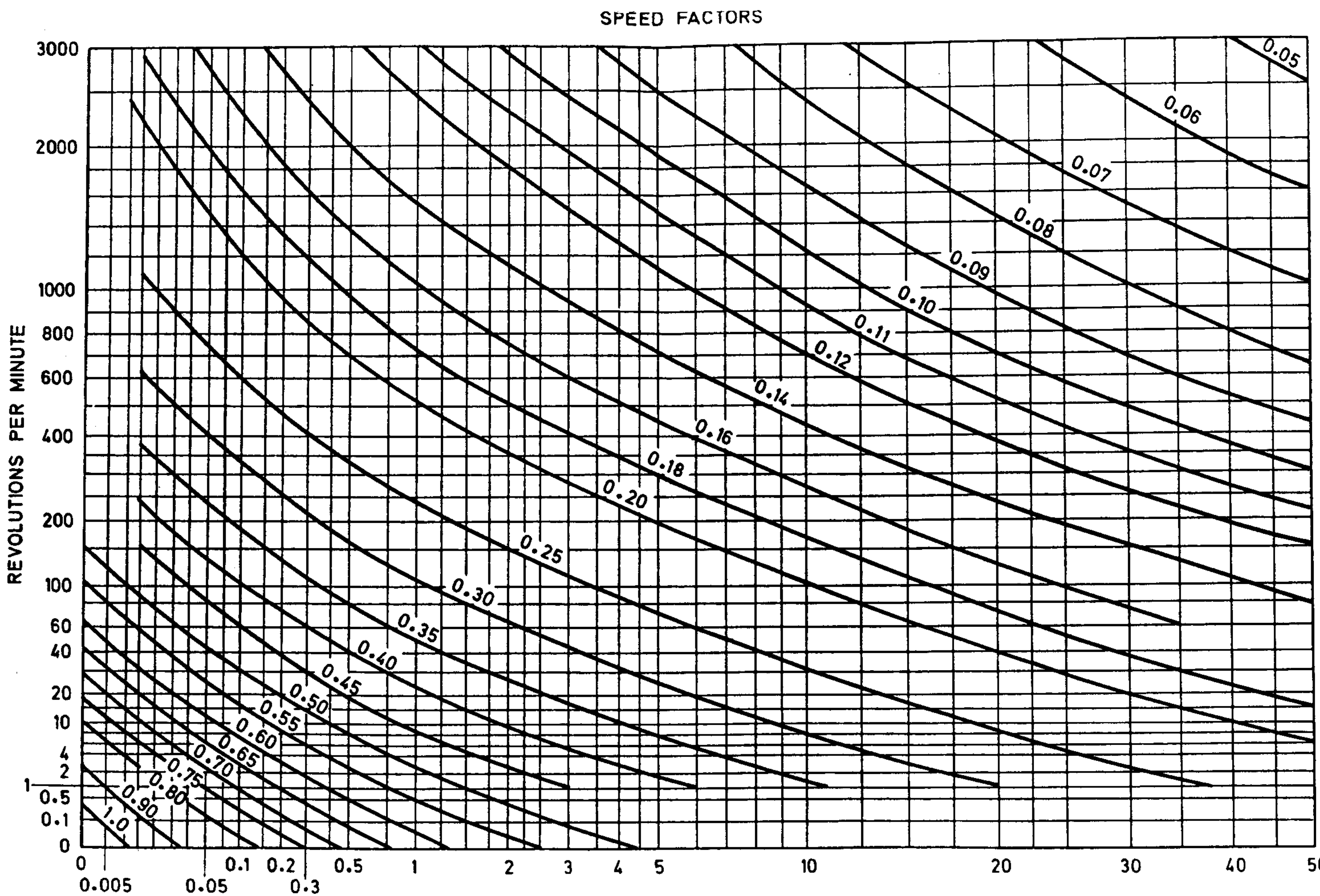
The speed factor X_c for wear corresponding to combination of rotational speed and rubbing speed shall be in accordance with Fig. 1. The speed factor X_b for strength corresponding to the rotational speed only shall be in accordance with Fig. 2.

5.3 Surface Stress Factor S_c

The surface stress factor S_c corresponding to the combination of materials used shall be in accordance with Table 1.

5.4 Bending Stress Factor S_b

The bending stress factor S_b corresponding to the material used shall be in accordance with Table 1.



Rubbing Speed in m/s

FIG. 1 SPEED FACTORS FOR WORM GEARS FOR WEAR X_c

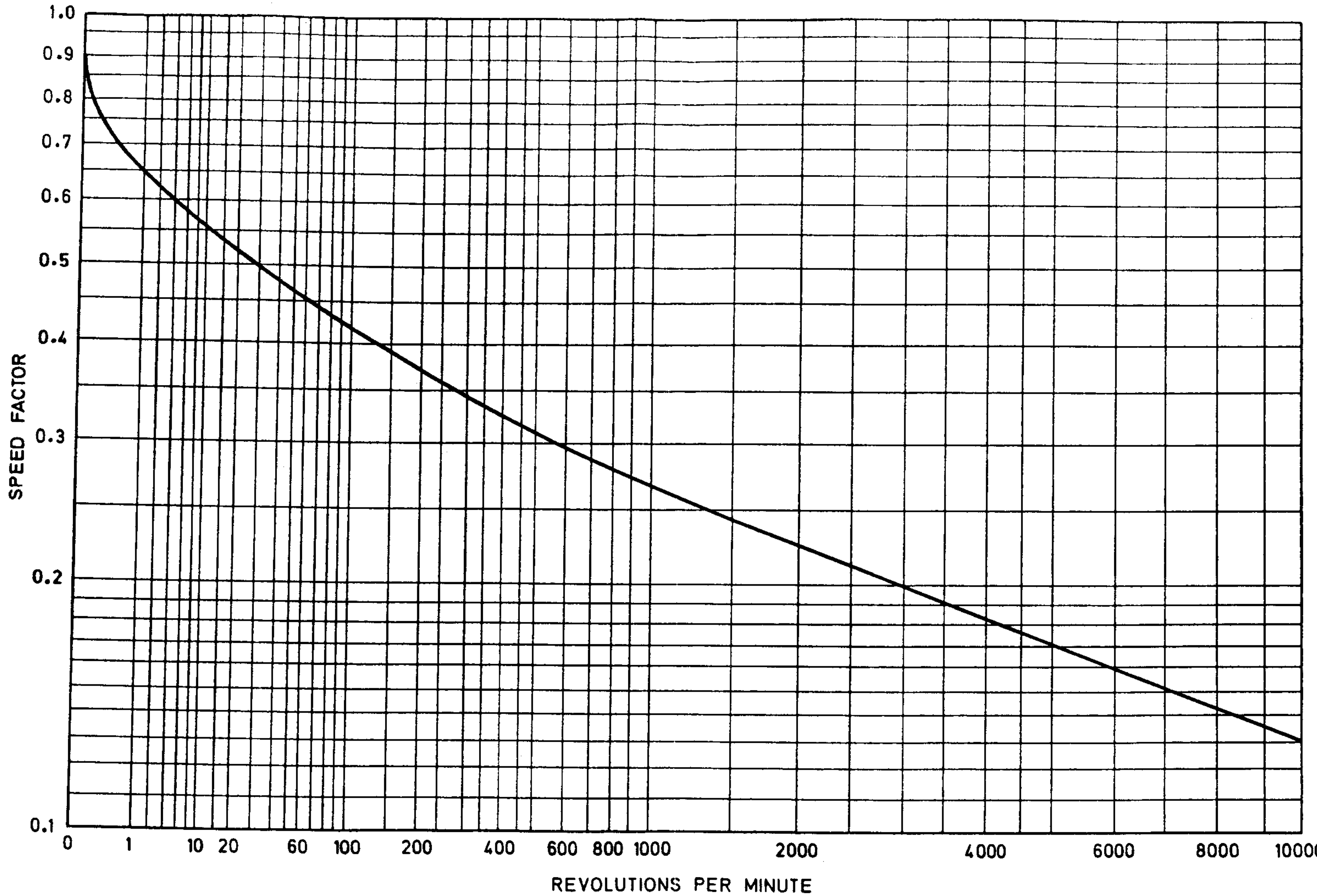


FIG. 2 SPEED FACTORS FOR WORM GEARS FOR STRENGTH X_s

Table 1 Stress Factors for Work Gears S_b and S_c
(*Clauses* 5.3 *and* 5.4)

Material		IS Reference	Bending Stress Factor, S_b	Surface Stress Factor, S_c When Running with				
				A	B	C	D	E
A	Phosphor bronze centrifugally cast	IS 28	69	—	8.31[1]	8.3	9	15.2
A	Phosphor bronze sand cast chilled	—	63	—	6.2[1]	6.2	6.9	12.4
A	Phosphor bronze sand cast	—	49	—	4.6[1]	4.6	5.3	10.4
B	Grey cast iron	Grade FG 200 IS 210	40	6.2[1]	4.1[1]	4.1[1]	4.1[1]	5.2[1]
C	0.4 % carbon steel normalised	40C8 IS 5517	138	10.8	6.9	—	—	—
D	0.55% carbon steel normalised	55C8 IS 5517	173	15.2	8.3[2]	—	—	—
E	Carbon case hardening steel	15C8 IS 4432	276	48.3	30.4[2]	—	—	15.2[2]
E	Nickel molybdenum case hardening steel	20Ni7Mo2 IS 4432	325	53.1	30.4[2]	—	—	15.2[2]
E	Nickel chromium case hardening steel	13Ni13Cr3 IS 4432	345	60.7	30.4[2]	—	—	15.2[2]

[1] Maximum permissible speed = 2.54 m/s.
[2] Permissible for hand motion only.

5.5 Normal Rating

The normal rating is the loading to which the gears may safely be subjected for a period of 12 h per day, for a total running time of 26 000 h. If it is necessary to design worm gears on the basis on any other life, the permissible power or worm wheel torque shall be multiplied by the following expressions:

a) For wear

$$\left[\frac{27\,000}{(1\,000 + t_{ec})}\right]^{1/3}$$

b) For strength

$$\left[\frac{26\,200}{(200 + t_{eb})}\right]^{1/7}$$

The values of these factors shall be obtained from Fig. 3. In case of operation with shock loads, service factors as indicated in IS 7403 are to be made use of.

5.6 Permissible Torque for Wear

For the normal rating the permissible torque on the worm wheel is limited by wear to the lower of the following two values:

a) $T_{c1} = 0.001\,91\, X_{c1}\, S_{c1}\, Y_z\, d_2^{1.8}\, m$

b) $T_{c2} = 0.001\,91\, X_{c2}\, S_{c2}\, Y_z\, d_2^{1.8}\, m$

5.6.1 The values of worm gear zone factor Y_z are given in Table 2.

5.7 Permissible Torque for Strength

For the normal rating the permissible torque on the worm wheel is limited by strength to the lower of the following two values:

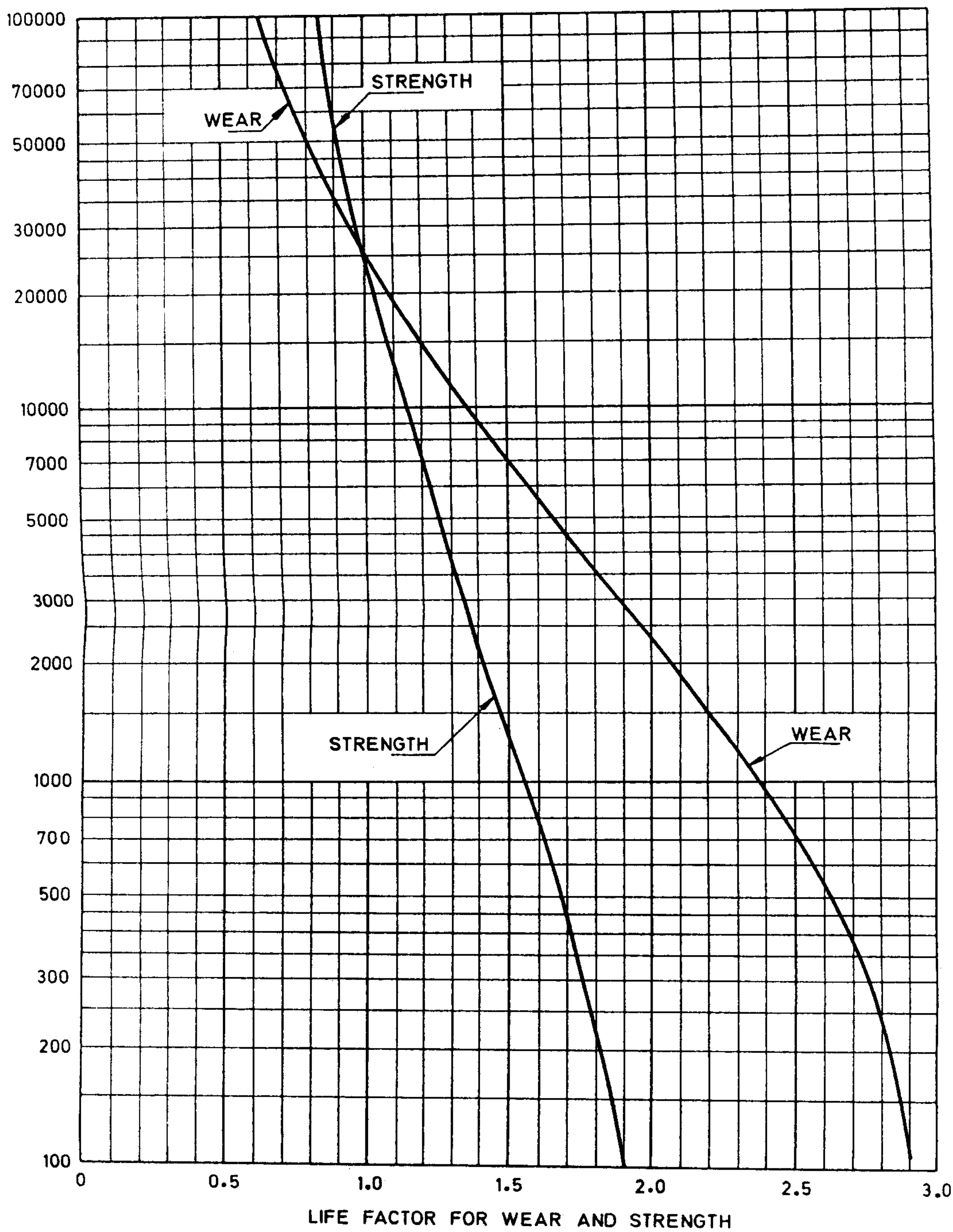


FIG. 3 LIFE FACTORS FOR WEAR AND STRENGTH

Table 2 Worm Gear Zone Factor, Y_z

(*Clause* 5.6.1)

Z \ q	6	6.5	7	7.5	8	8.5	9	9.5	10	11	12	13	14	16	17	18	20
									Y_Z								
1	1.045	1.048	1.052	1.065	1.084	1.107	1.128	1.137	1.143	1.160	1.202	1.260	1.318	1.374	1.402	1.437	1.508
2	0.991	1.028	1.055	1.099	1.144	1.183	1.214	1.223	1.231	1.250	1.280	1.320	1.360	1.418	1.447	1.490	1.575
3	0.822	0.890	0.969	1.109	1.209	1.260	1.305	1.333	1.350	1.365	1.393	1.422	1.442	1.502	1.532	1.580	1.674
4	0.826	0.883	0.981	1.098	1.204	1.301	1.380	1.428	1.460	1.490	1.515	1.545	1.570	1.634	1.666	1.710	1.798
5	0.947	0.991	1.050	1.122	1.216	1.315	1.417	1.490	1.550	1.610	1.632	1.652	1.675	1.735	1.765	1.805	1.886
6	1.132	1.145	1.172	1.220	1.287	1.350	1.438	1.521	1.588	1.675	1.694	1.714	1.733	1.789	1.818	1.854	1.928
7			1.316	1.340	1.370	1.405	1.452	1.540	1.614	1.704	1.725	1.740	1.760	1.817	1.846	1.880	1.950
8					1.437	1.462	1.500	1.557	1.623	1.715	1.738	1.753	1.778	1.838	1.868	1.898	1.960
9							1.573	1.604	1.648	1.720	1.743	1.767	1.790	1.850	1.880	1.910	1.970
10									1.680	1.728	1.748	1.773	1.798	1.858	1.888	1.920	1.980
11										1.732	1.753	1.777	1.802	1.862	1.892	1.924	1.987
12											1.760	1.780	1.806	1.866	1.895	1.927	1.992
13												1.784	1.808	1.867	1.898	1.931	1.998
14													1.811	1.871	1.900	1.933	2.000

NOTES

1 The values are based on $b = 2m\sqrt{(q+1)}$, symmertrical about the centre plane of the wheel.

2 For smaller face widths the value of Y_z must be reduced proportionately.

3 When it is necessary to obtain greater load capacity the worm wheel face width may be increased up to a maximum of 2.3 $m\sqrt{(q+1)}$ and the zone factor increased proportionately.

4 The table applied to worm wheels having 30 teeth; variation in the number of teeth produce negligible changes in the value of Y_z.

a) $T_{b1} = 0.001\,8\,X_{b1}\,S_{b1}\,m\,l_r\,d_2\,\mathrm{Cos}\,\tau$

b) $T_{b2} = 0.001\,8\,X_{b2}\,S_{b2}\,m\,l_r\,d_2\,\mathrm{Cos}\,\tau$

where

$$l_r = (d_{a1} + 2c)\sin^{-1}\frac{b}{(d_{a1} + 2c)}$$

the angle is in radians

$$d_{a1} = m\,(q + 2)$$

$$c = 0.2\,m\,\mathrm{Cos}\,\tau$$

$$b = 2\,m\,\sqrt{(q+1)}$$

6 RATING OF WORM WHEEL

6.1 Power

Subject to the provisions of working temperature (*see* **6.2**), the normal power rating (in kW) of the worm wheel is given by:

$$\frac{Tn_2}{9\,550}$$

where T is the smallest of the four values obtained in accordance with **5.6** and **5.7** and n_2 is the number of revolutions per minute of worm wheel.

6.2 Working Temperature

The continuous rating of worm gear operating in still air may be limited by consideration of temperature rise rather than by resistance to bending or surface stresses.

6.2.1 Where the working oil temperature of 95°C is exceeded the maximum permissible torque on the worm wheel may be less than that indicated in **5.6** and **5.7**.

6.3 Efficiency and Lubrication

The efficiency (excluding bearing and oil-churning losses) of gears is given by :

$$E\text{ (Worm driving)} = \frac{\tan\tau}{\tan(\tau + \phi)} \times 100$$

$$\text{E (Worm wheel driving)} = \frac{\tan(\tau - \phi)}{\tan\tau} \times 100$$

where

$\tan\phi$ is the co-efficient of friction between worm and worm wheel corresponding to the rubbing speed which can be obtained from Fig. 4.

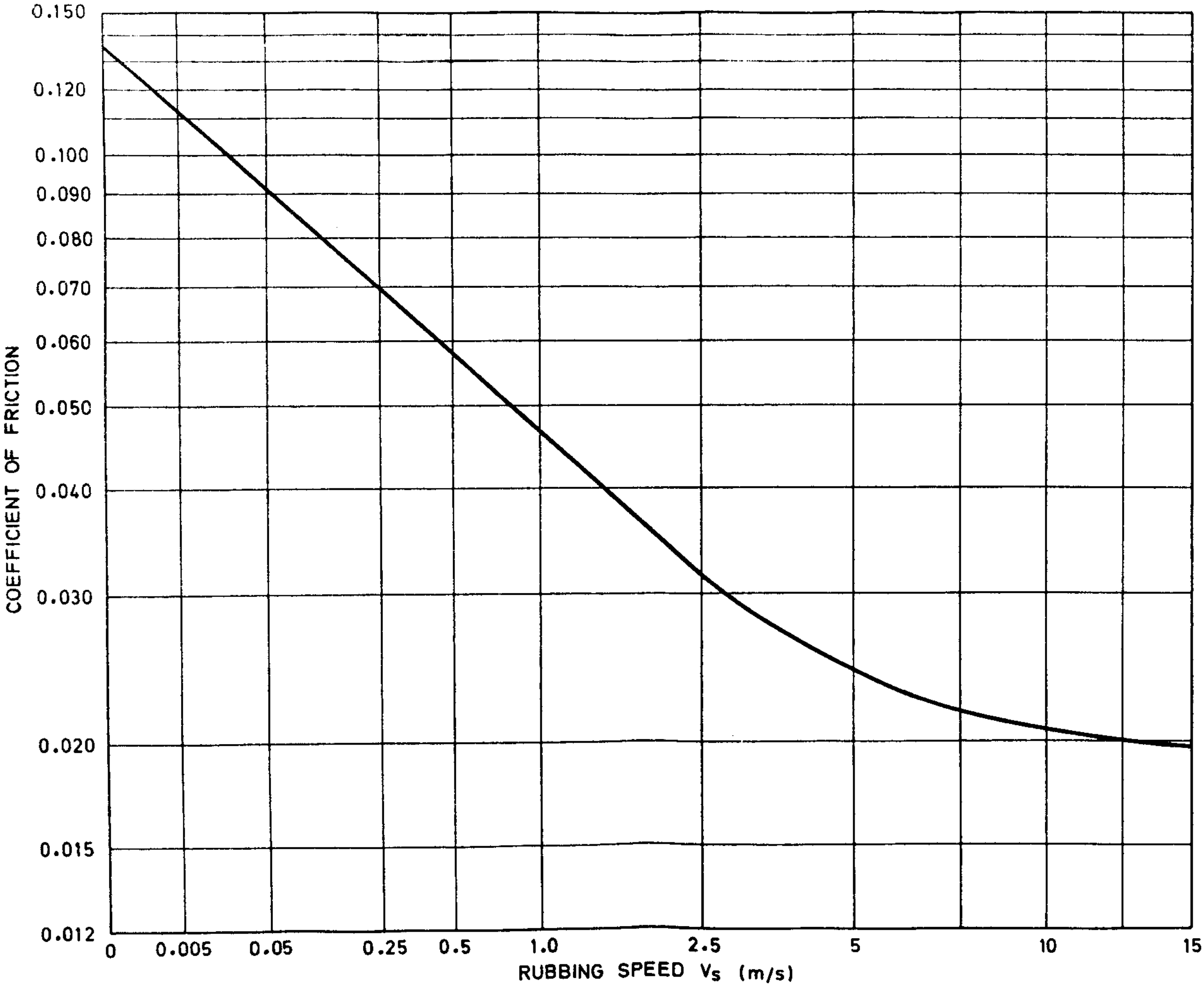


FIG. 4 COEFFICIENT OF FRICTION FOR WORM GEARS

The values of the co-efficient of friction given in Fig. 4 are based on the use of phosphor bronze wheels and case hardened, ground and polished steel worms, lubricated by a mineral oil having a viscosity between 60 mm²/s and 130 mm²/s (60 cSt and 130 cSt) at 60°C (250 s and 500 s Redwood at 140°F).

6.4 Momentary Overload Capacity

The load whose duration is too short to be defined with certainty shall be considered to act for a period of not more than 15 s.

6.4.1 Worm gears designed in accordance with this standard shall be capable of transmitting occasional momentary loads not exceeding the values calculated from either of the following:

a) $T_{cm} = 0.003\,82\, S_{c2}\, Y_z\, d_2^{1.8}\, m$

b) $T_{bm} = 0.004\, S_{b2}\, l_r\, d_2\, m \cos\tau$

7 DETERMINATION OF EQUIVALENT RUNNING TIME FOR LOADING CONDITION OTHER THAN A STEADY LOAD

7.1 The cycles of different uniform loads at different speeds are given in Fig. 5.

7.1.1 If the load cycle on the worm wheel comprises a maximum torque T_1 acting for t_1 hour at a mean speed of n_1 and smaller torques T_2, T_3 ..etc., acting for t_2, t_3, ..etc, hours at mean speeds n_2, n_3, ...etc., the equivalent running time per cycle for wear at torque T_1 and speed n_1 is given by:

$$t_{em} = t_1 + t_2\left[\frac{n_2}{n_1}\right]\left[\frac{T_2}{T_1}\right]^3 + t_3\left[\frac{n_3}{n_1}\right]\left[\frac{T_3}{T_1}\right]^3 + \text{...etc}$$

in which each term represents the equivalent running time for the corresponding part of the cycle.

7.1.2 The total equivalent running time for wear at torque T_1 and worm wheel speed n_1 is then given by :

t_{cc} = t_{cm} × Number of complete cycles expected during the life of the gears

7.1.3 The equivalent running time per cycle for strength at torque T_1 and worm wheel speed n_1 is then given by:

$$t_{bm} = t_1 + t_2 \left[\frac{n_2}{n_1}\right]\left[\frac{T_2}{T_1}\right]^7 + t_3 \left[\frac{n_3}{n_1}\right]\left[\frac{T_3}{T_1}\right]^7 + \text{...etc}$$

in which each term represents the equivalent running time for the corresponding part of the cycle.

7.1.4 The total equivalent running time for strength at torque T_1 and worm wheel speed n_1 is then given by:

t_{cb} = t_{bm} × Number of complete cycles expected during the life of the gears.

7.2 Irregular Variation of Load and Variable Speeds

The equivalent running time for a period of the load cycle under **7.1** during which load and speed vary other than uniformly shall be determined by subdividing it into periods during none of which the torque changes by more than $T_1/4$. The equivalent running time for wear and strength corresponding to each such period on the basis of the mean load and the mean speed during the period shall be calculated in accordance with **7.1**.

7.3 Uniform Variation of Load and Variable Speeds

If during any period t of the load cycle under **7.1** the torque changes uniformly from T_{t1} to T_{t2} at mean speed n_m, the expression of the equivalent running time in hour per cycle for wear at torque T_1 and speed n_1 is given by:

$$t_{em} = \frac{t}{4}\left[\frac{n_m}{n_1}\right]\left[\frac{T_{t1}}{T_1} + \frac{T_{t2}}{T_1}\right] \times \left[\left[\frac{T_{t1}}{T_1}\right]^2 + \left[\frac{T_{t2}}{T_2}\right]^2\right]$$

The equivalent running time for strength at torque T_1 and speed n_1 is given by:

$$t_{bm} = \frac{t}{8}\left[\frac{n_m}{n_1}\right]\left[\frac{T_{t1}}{T_1} + \frac{T_{t2}}{T_1}\right] \times \left[\left[\frac{T_{t1}}{T_1}\right]^2 + \left[\frac{T_{t2}}{T_1}\right]^2\right]\left[\left[\frac{T_{t1}}{T_1}\right]^4 + \left[\frac{T_{t2}}{T_1}\right]^4\right]$$

7.4 Load Varying in a Cycle Which is Repeated a Whole Number of Times in One Revolution of the Worm Wheel

If a whole number of load cycles are completed in exactly one revolution of the worm wheel, then the gear shall be designed to transmit the maximum torque continuously for an equivalent time equal to the expected running life of the gears.

8 PARAMETERS OF WORM GEARS

These shall be based on IS 3734.

9 EXAMPLES OF CALCULATION

These are given in Annex A.

ANNEX A

(*Clause* 9)

EXAMPLES OF CALCULATION

A-1 POWER CALCULATION

A-1.1 To find the power ratings for wear and strength of the gears having designation R2/30/10/10/200 and input speed 1 000 rev/min.

The permissible torque is limited by the lower of the following two values for wear:

a) $T_{c1} = 0.001\ 91\ X_{c1}\ S_{c1}\ Y_z\ d_2^{1.8}\ m$

b) $T_{c2} = 0.001\ 91\ X_{c2}\ S_{c2}\ Y_z\ d_2^{1.8}\ m$

For centrifugally cast phosphor bronze worm wheel and a nickel-molybdenum case hardening steel worm

$$S_{c1} = 53.1$$
$$S_{c2} = 15.2$$
$$S_{b1} = 325$$
$$S_{b2} = 69$$
$$Y_z = 1.231$$
$$d_2 = 2\left(200 - \frac{100}{2}\right) = 300 \text{ mm.}$$

Rubbing speed

$$V_s = 0.000\ 052\ 4 \times d \times n \times \text{Sec}\ \tau \text{ m/s}$$
$$V_s = 0.000\ 052\ 4 \times 100 \times 1\ 000 \times \text{Sec}\ 11.316\ 6 \text{ m/s}$$
$$= 5.34 \text{ m/s.}$$

From Fig. 1 $\quad X_{c1} = 0.125, \quad X_{c2} = 0.24$

$$T_{c1} = 0.001\ 91 \times 0.125 \times 53.1 \times 1.231 \times 300^{1.8} \times 10 \text{ Nm} = 4\ 489 \text{ Nm}$$

$$T_{c2} = 0.001\ 91 \times 0.24 \times 15.2 \times 1.231 \times 300^{1.8} \times 10 \text{ Nm} = 2\ 467 \text{ Nm}$$

The permissible torque values for strength are given by:

a) T_{b1} 0.001 8. $X_{b1}\ S_{b1}\ m\ lr\ d_2$ Cos τ

b) T_{b2} 0.001 8. $X_{b2}\ S_{b2}\ m\ lr\ d_2$ Cos τ

From Fig. 2

$$X_{b1} = 0.27 \qquad X_{b2} = 0.45$$

$$l_r = (d_{a1} + 2c) \sin^{-1}\left[\frac{b}{d_{a1} + 2c}\right]$$

and

$$d_{a1} = m\,(q + 2) = 10\,(10 + 2) = 120$$
$$c = 0.2\,m \text{ Cos}\,\tau = 0.2 \times 10 \times \text{Cos}\ 11.316\ 6$$
$$= 1.96$$
$$b = 2m\sqrt{q+1} = 2 \times 10\sqrt{10+1} = 66.33$$
$$l_r = 123.92 \sin^{-1}\left[\frac{66.33}{123.92}\right]$$
$$= 123.92 \times 0.564\ 8 = 69.993$$

therefore

$$T_{b1} = 0.001\ 8 \times 0.27 \times 325 \times 10 \times 69.993 \times 300 \times \text{Cos}\ 11.316\ 6 \text{ Nm}$$
$$= 32\ 521 \text{ Nm}$$
$$T_{b2} = 0.001\ 8 \times 0.45 \times 69 \times 10 \times 69.993 \times 300 \times \text{Cos}\ 11.316\ 6 \text{ Nm}$$
$$= 11\ 508 \text{ Nm.}$$

The permissible torque is limited by the minimum of T_{c1}, T_{c2}, T_{b1} and T_{b2} viz, 2 467 Nm on worm wheel therefore,

$$\text{Normal power rating} = \frac{2\ 467 \times 1\ 000}{15 \times 9\ 550} = 17.22 \text{ kW}$$

A-2 Determination of uniform loading equivalent to specified varying loading duty comprising of 700 cycles per day. Each cycle being made up of following periods:

Period 1

Torque falls uniformly from	: 2 150 Nm to 1 275 Nm
Time occupied	: 3 s
Mean speed	: 16 rpm

Period 2

Torque (constant)	: 880 Nm
Time occupied	: 10 s
Mean speed	: 32 rpm

Period 3

Torque fall uniformly from	: 3 330 Nm to 2 150 Nm
Time occupied	: 2 s
Mean speed	: 16 rpm
Normal torque rating	: 3 300 Nm
Speed	: 16 rpm

A-2.1 Calculation of Equivalent Times and Life Factor for Wear

Period 1

$$t_{em1} = \frac{3}{3\ 600 \times 4}\left[\frac{16}{16}\right]\left[\frac{2\ 150}{3\ 330} + \frac{1\ 275}{3\ 330}\right]\left[\left[\frac{2\ 150}{3\ 330}\right]^2 + \left[\frac{1\ 275}{3\ 330}\right]^2\right]$$
$$= 1.208 \times 10^{-4} \text{ h}$$

Period 2

$$t_{em2} = \frac{10}{3\,600 \times 4}\left[\frac{32}{16}\right]\left[\frac{880}{3\,330}\right]^3 \times 4$$

$$= 1.025 \times 10^{-4} \text{ h}$$

Period 3

$$t_{em3} = \frac{2}{3\,600 \times 4}\left[\frac{16}{16}\right]\left[\frac{3\,330}{3\,330} + \frac{2\,150}{3\,330}\right]$$

$$\left[\left[\frac{3\,330}{3\,330}\right]^2 + \left[\frac{2\,150}{3\,330}\right]^2\right]$$

$$= 3.23 \times 10^{-4} \text{ h}$$

Total equivalent running time per day

$$= 700 \times 5.463 \times 10^{-4} = 0.383 \text{ h}$$

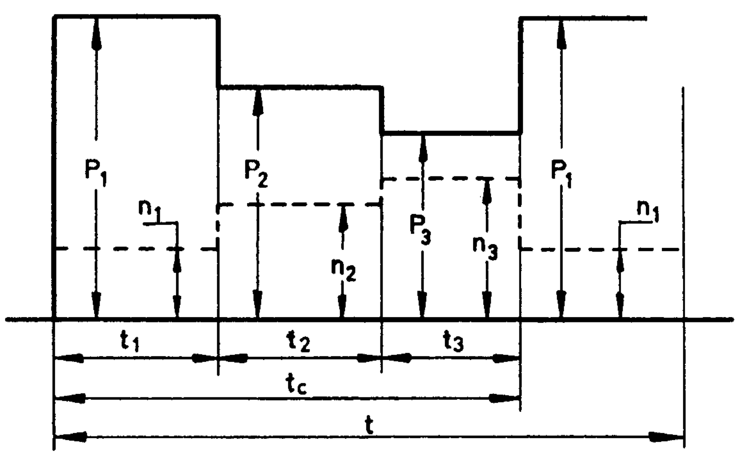
$$\text{Life} = \frac{26\,000}{12} \times 0.383 = 830 \text{ h}$$

Life factor for wear = 2.45 (*see* Fig. 3)

Hence, the gear must be designed for a normal

Torque rating for wear = $\frac{3\,330}{2.45}$ = 1 359 Nm of wheel

Shaft torque at 16 rpm = 2.28 kW



When the load variation is of the form shown in Fig. 5A with loads ($P_1 . n_1 . t_1 : P_2 . n_2 . t_2 : P_3 . n_3 . t_3$) and with the time of the working cycle $t_c = t_1 + t_2 + t_3$, the equivalent time will be:

$$t_e = t_1 + t_2\left[\frac{n_2}{n_1}\right]\left[\frac{(P_2)^3}{P_1}\right] + t_3\left[\frac{n_3}{n_1}\right]\left[\frac{(P_3)^3}{P_1}\right] \text{h/cycle}$$

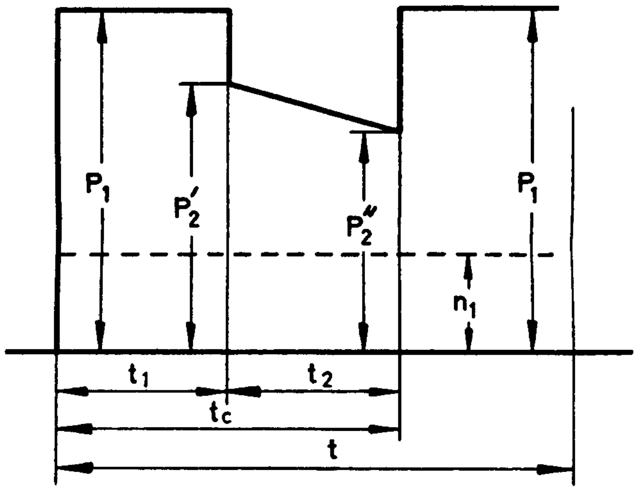
where

P = load in N,

n = speed in rpm, and

t = time in hours.

5A



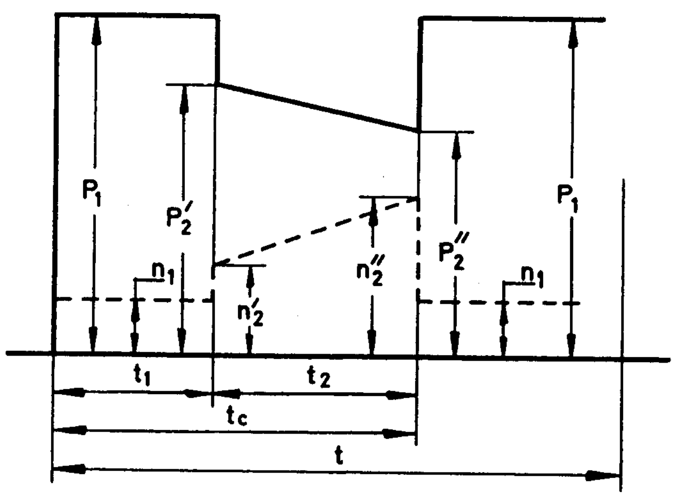
If the load varies linearly during constant speed as shown in Fig. 5B, the equivalent time will be:

$$t_e = t_1 + \frac{t_2}{4}\left[\frac{P_2'+P_2''}{P_1}\right]\left[\left[\frac{P_2'}{P_1}\right]^2+\left[\frac{P_2''}{P_1}\right]^2\right]\text{h/cycle}$$

where

P = load in N,
n = speed in rpm, and
t = time in hours.

5B



During linear variation of load linear variation of speed as shown in Fig. 5C, the equivalent running time will be :

$$t_e = t_1 + t_2\left[\frac{n_2'+n_2''}{2n_1}\right]\left[\frac{P_2'+P_2''}{P_1}\right]\left[\left[\frac{P_2'}{P_1}\right]^2+\left[\frac{P_2''}{P_1}\right]^2\right]\text{h/cycle}$$

where

P = load in N,
n = speed in rpm, and
t = time in hours.

5C

FIG. 5 CYCLES OF LOADS AT DIFFERENT SPEEDS

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Review of Indian Standards

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BUREAU OF INDIAN STANDARDS

Headquarters:

Manak Bhavan, 9 Bahadur Shah Zafar Marg, New Delhi 110 002
Telephones : 323 01 31, 323 33 75, 323 94 02

Telegrams : Manaksanstha
(Common to all offices)

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Eastern	: 1/14 C.I.T. Scheme VII M, V. I. P. Road, Kankurgachi KOLKATA 700 054	337 84 99, 337 85 61 337 86 26, 337 91 20
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